DIVE BEHAVIOR, HAULOUT PATTERNS, AND MOVEMENTS OF HARBOR SEAL PUPS IN THE KODIAK ARCHIPELAGO, 1997-2000

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INTRODUCTION

Harbor seal numbers on Tugidak Island, south of Kodiak Island, declined sharply 85% from the 1976-1988, whereas during the recent 1994-1999 period seal numbers increased 4.9% annually (Pitcher 1990, Jemison and Pendleton 2001). Seal numbers along the east side of the Kodiak Archipelago have followed similar trends, with a current 5.6% annual rate of increase for the 1993-1999 period (Lewis *et al*. 1996, Small *et al.* 2001). Over the past decade, several studies have been conducted on Tugidak Island to better understand harbor seal biology and to examine what factors may be influencing their population dynamics (e.g., Daniel *et al*. 2001, Hastings *et al*. 2001, Jemison and Kelly 2001, Jemison and Pendleton 2001). This progress report summarizes the data collected during our study of the movement and dive behavior of harbor seal pups born on Tugidak Island during 1997-2000. We had three general objectives for this report: (1) describe the spatial and temporal patterns of haulout usage, (2) describe pup movement and development of diving behavior during the first year of life, and (3) describe the areas and depths used for feeding by harbor seals for comparison with habitat variables (e.g., Coyle 2001). The data presented in this report, and subsequent statistical analyses, will provide information to the U. S. National Marine Fisheries Service (NMFS) that can be used for designing a conservation and management program for harbor seals in Alaska.

Harbor seal pups alternate spending periods of time resting on land, at so-called "haulout sites", with intervals at sea. While at sea prior to weaning, pups remain with their mothers when transiting between haulouts and foraging areas, or diving but not capturing prey. Pups begin diving with their mothers as early as 0-3 days post partum (Bowen *et al*. 1999), though early pup dives are not as deep or long as adult female dives. Weaning occurs 3-5 weeks post-partum (Johnson 1976), after which increased diving effort is expected.

We examined haulout attendance data to describe the temporal patterns of haulout usage, whereas spatial patterns of haulout usage were described by combining location data with haulout sensor data. Since haulouts serve as focal points for the at-sea foraging trips of harbor seals, changes in the spatial distribution of haulouts used over time may help corroborate other indications of foraging in a particular area. Distances between consecutive haulout bouts are a minimum measure of animal movement.

Dive data describe the development of diving behavior and capability over the first year of life, and where it is possible to classify by geographic area, may also indicate locations and depths used for foraging. Location data describe the areal extent of harbor seal pup activity from their natal area on Tugidak Island. Locations also identify concentrations of activity at-sea. The spatial extent of foraging trips, as indicated by location data, provides another possible measure of changes in foraging effort over time.

This progress report also describes the characteristics and quality of satellite-acquired movement, haulout, and dive behavior data collected between June 1997 and July 2000, including completeness and limitations of these data. Several summaries of the various data types are presented to provide an initial overview that will be explored further during a more comprehensive statistical analysis to begin during the 2001-2002 contract period.

METHODS

Capture and Tagging

Seventy-two harbor seal pups (45 male, 27 female) were captured at four sites on Tugidak Island, Southwest Beach, Middle Beach, North Beach, and North-Northeast Beach (Figure 1), during the last week of June in 1997, 1998, and 1999 (Table 1). Seals were netted as they rested on the haulout and manually restrained to obtain measurements, attach instruments, apply flipper tags, and collect biological samples prior to release. We deployed 28 Type 3 satellite-linked time-depth recorders (SDRs), manufactured by Wildlife Computers, Inc., on 16 male and 12 female pups; 10 in 1997, 9 in both 1998 and 1999 (Table 2). These epoxy-cast SDR units contained a pressure transducer to record depth, conductivity sensors to indicate whether the unit was wet or dry, a user-programmable control processor, and a satellite radio transmitter (Model T-6 Platform Transmitter Terminal, Telonics, Inc.). Twenty-two units were equipped with 2/3 amp batteries, providing an expected lifetime of 15,000 transmissions, and 7 were equipped with Type-M1 batteries, which provided 20,000 transmissions. SDRs were attached to the mid-dorsal fur of harbor seal pups using 5-Minute Epoxy (Devcon, Inc.) over a mesh-netting base.

SDR Programming

SDRs deployed in late June could potentially remain attached for about one year because pups would not molt until the following June or July. We therefore programmed SDRs conservatively to extend battery life for 12-13 months. Units transmitted on a duty cycle permitting transmission on alternate days only. During “on” days, SDRs were limited to 100 data transmissions, or "messages", per day. During “off” days, SDRs did not transmit, but continued to collect and store dive and haulout data. Messages were transmitted every 40 seconds when at-sea to maximize chances of location calculation, and every 90 seconds when the animal was on a haulout to conserve power. All transmission was temporarily disabled after animals were hauled out for >2 continuous hours.

SDRs transmitted messages, encoded with a unique identifier, on a single radio frequency to the Argos instruments aboard 3-4 U. S. National Oceanic and Atmospheric Administration polar-orbiting satellites (Harris *et al*. 1990). The SDRs were programmed to transmit only during the hours with highest probability of satellite overpass, which were 13:00-18:00 and 22:00-03:00 Universal Time (UT) in our Kodiak study area. These messages relayed the diving and haulout behavior data collected by the SDRs to the Argos system. When $\geq$ 2 messages were received during a single satellite overpass, the Argos system attempted to calculate the SDR location and assigned an accuracy estimate. Locations were calculated using a combination of known satellite position, known position of the Earth's surface, and the distance between the SDR and the satellite as computed from the Doppler-shift of the SDR radio signal. Accuracy estimates computed by Argos ranged from <150 meters to "unknown". Although the Argos satellite data relay system provides global and frequent coverage, it has several limitations. Transmissions are one-way only, such that SDRs are not able to confirm that their transmitted data were received. Transmissions are also restricted to 32 sensor data bytes each. SDRs are designed to best accommodate these limitations by summarizing dive and haulout data before transmission, and transmitting each data unit redundantly. Data collected in this fashion are not guaranteed to be continuous, and lack the fine temporal resolution of traditional time-depth recorders (TDRs).

Four 6-hour histograms (sampling units) of summarized dive data were collected per day (Local Time): "dawn", 03:00 – 08:59:59, "day", 09:00 - 14:59:59; "dusk", 15:00 – 20:59:59; and "night", 21:00 – 02:59:59 the following day. Local Time (LT) was defined as local longitudinal time (Wildlife Computers, Inc. 1997), 11 hours behind UT in the Tugidak Island area, and more closely resembled the actual solar cycle than Alaska Standard Time. Three types of summarized dive behavior data were collected: Maximum Depth, Duration, and Time-at-Depth. SDRs recorded all dives > 4 meters deep. Seal activity at depths shallower than 4 meters were excluded. Because these SDRs record depths with a resolution of 2 meters, we selected a dive threshold of at least 4 meters deep to avoid mis-classifying at-surface swimming behavior as an actual, focused dive event.

Maximum Depth histograms counted the number of dives during a 6-hour period which reached a maximum depth within one of 10 bins: <10 meters, 12-20 m, 22-36 m, 38-50 m, 52-76 m, 78-100 m, 102-150 m, 152-200 m, 202-250 m, and >250 m (bins do not appear inclusive because the SDRs record depths at a 2 meter resolution). Duration histograms counted the number of dives during a 6-hour period which lasted a given number of minutes: 0-1 min, 1-2 min, 2-3 min, 3-4 min, 4-5 min, 5-6 min, 6-8 min, 8-10 min, 10-12 min, and > 12 min. Time-at-Depth histograms provided the proportion of each 6-hour period that an animal spent within a given depth range: at-surface (conductivity sensor was dry), 0-4 m, 6-10 m, 12-20 m, 22-36 m, 38-50 m, 52-76 m, 78-100 m, 102-150 m, and >150 m. The maximum absolute depth reached by an animal during a given 24-hour period was also recorded, but received less frequently. The SDR's 2-meter depth resolution and 490 meter recording capability limited this maximum depth value.

SDRs also provided 3 methods for estimating haulout behavior. The most reliable, but least complete, was the haulout status indicator (or "Land/Sea Data") sent with most transmissions. These indicators had strict definitions that reduced false-positive haulout readings: "haulout" status begins only after 400 continuous seconds of dry conductivity sensor readings, and "at-sea" status begins after 360 seconds wet. These data are especially useful for classifying Argos locations as either on-land or at-sea. Unfortunately, these data were received at irregular intervals, limited to those time periods when the SDR is programmed to transmit, and subject to loss because they were not stored and transmitted redundantly.

A more complete but somewhat less absolute measure of haulout behavior was the "At-Surface Timeline". Conductivity sensor status ("wet" or "dry") was sampled every 10 seconds, and each 20-minute interval (72 intervals for each 24-hour period) was assigned the majority value of its sensor readings, wet or dry. The major advantage of this method was that timelines were transmitted in a highly redundant fashion; each timeline was transmitted for 2 full transmit-days. Resampling the data into 20-minute intervals also provided some protection from false-positive haulout readings. This was also the only method that allowed haulout bout start/stop times to be identified reliably. SDRs used in previous harbor seal studies lack this recent innovation.

A summarized measure of haulout behavior was provided by the Time-at-Depth dive histogram. The proportion of time an SDR spent at the surface (dry) during each 6-hour histogram period was recorded. This method was most susceptible to false-positive haulout readings, because it included all time spent at-surface (including time spent at-sea with the SDR exposed) without the built-in checks of surface-timeline and land/sea data.

Data Extraction and Summary

Data relayed from the SDRs were received from Argos/CLS every month. We used the Argos/CLS "Location Service Plus", which provided a primary and alternate solution for each location, numerous diagnostic indicators of signal quality, and locations that fail the standard Argos quality tests (Argos/CLS 1996). This service allowed us to select the correct location solution (primary or alternate) for each location fix, and avoid the 6% error caused when this selection is performed automatically by Argos/CLS. Since our SDRs are of relatively low power compared to most Argos transmitters, many of our locations fail standard Argos quality checks. However, through the editing process described below, we are able to make use of many of these locations that would otherwise be discarded by the Argos system.

We used the SATPAK software package (Wildlife Computers, Inc. 2000**)** to process raw Argos data files and extract locations. With SATPAK we identified the correct primary/alternate solution for each location fix. SATPAK was also used to extract haulout timelines, land/sea data, daily maximum depth readings, maximum dive depth histograms, duration histograms, time-at-depth histograms, and SDR status diagnostic reports. SATPAK also returned a set of unreadable, corrupted data messages for possible repair.

We edited the location data using the SATEL program, a Microsoft FoxPro application created for the Alaska Department of Fish and Game (ADF&G) by Robert Delong, following procedures developed by Frost *et al.* (1995). First, locations classified invalid by Argos (Location Class “Z”) were deleted. Next, the Keating error index (Keating 1994) was computed for all locations, and locations with index value > 25 were deleted. Next, locations which exceeded the reasonable movement capabilities of harbor seals were deleted, in sequence: movements of > 10 km/h for > 5 minutes; movements of > 100 km/h for >1 minute; and any movement of > 500 km/h. Finally, we re-computed the Keating error index for the remaining locations, and deleted those locations with index value > 25. We did not arbitrarily remove valid locations from the data set based on Argos Location Class alone.

Screened locations were merged with the “Land/Sea” sensor data to classify them as on-land, at-sea, or unknown haulout status. For each day, the average location of the “on-land” locations and average location of the “at-sea” locations for each harbor seal was calculated. These average daily locations were imported into a relational database (Microsoft Access) for further analysis and query. Locations were extracted from the database into a geographic information system (ArcView) as needed for spatial analysis. Haulout, dive, and SDR diagnostic data were also archived in the database. Various database queries were performed to provide data for analysis and presentation in spreadsheet (Microsoft Excel) and statistical (S-Plus) software.

We assigned "on-land" mean daily locations to the nearest known haulout location within 5 km. Mean daily "on-land" locations that were tightly clustered along the shoreline, but were not near a known haulout, were identified as "potential haulouts". We calculated the straight-line distance between consecutive haulouts used by each animal to obtain a minimum estimate of animal movement and site fidelity.

We plotted our data over an improved version of the Alaska 1:63,360 shoreline, digitized from USGS topographic map quadrangles by the Alaska Department of Natural Resources (1998). Known haulout locations were those identified by NMFS and ADF&G population assessment aerial surveys. We overlaid at-sea Argos locations with a 2-minute resolution bathymetry grid (Smith and Sandwell 1997) for a rough estimate of location distribution by depth category. All spatial data were on the WGS 1984 datum, reprojected to Universal Transverse Mercator Zone 5.

RESULTS AND DISCUSSION

Instrument Performance and Data Completeness

Excluding 2 units that failed immediately after deployment (99-02, no messages ever received, and 97-07, messages ceased after 3 days), the SDRs remained active for a mean of 277 days (SD = 106), with deployments ranging from 29 to 384 days. The 7 Type M1 battery equipped SDRs functioned a mean of 317 days (SD = 86), while the 19 2/3-amp battery equipped SDRs functioned a mean of 263 days (SD = 111). SDRs operated for 7,291 deployment-days during the period of June 1997 through July 2000.

SDRs broadcast a mean (by seal) of 74 messages per transmit-day (range 50-95), limited by a 100-message daily quota. Of transmissions made, 13.3% (mean by seal; range 3.1-38.7%) were received and processed by the Argos system. This message loss may be due to: the absence of a satellite overhead at transmission time, improper orientation of the SDR antenna, re-entry into the water before transmission was complete, signal blockage by obstacles, competition from other signals, limited signal power, and instrument failure. It is important to note this transmission efficiency when designing future studies.

The Argos system fixed a mean of 2.0 (SD = 0.7) locations per transmission-day. Overall location quality, as estimated by the Argos system, showed that 51.1% of locations recorded on-land had accuracy better than 1 km, while only 21.2% of at-sea locations were as accurate (Table 3). Whereas seals spent 39.6% of their time at-sea, as indicated by surface timeline data, at-sea fixes accounted for over 87% of location data. SDRs equipped with Type M1 batteries had 28.4% locations with accuracy better than 1 km, whereas 23.4% of locations from 2/3-amp battery-equipped were as accurate.

We received 19,046 dive data histograms during the 7,291 days SDRs were active. There did not appear to be bias in the relative success of histogram reception by histogram type (Table 4), as we received Maximum Depth, Duration, and Time-at-Depth histograms for about 21.5% of their respective possible total periods. Histogram success was not dependent on time-of-day. We received maximum daily depth readings (at 2 meter resolution) for 2,974 days.

We received 1,040 discrete surface-timeline intervals, which ranged from 1 to 14 days in length. Timeline data covered 2,020 days, 27.7% of the possible total. Most (88%) timelines were ≤3 days in length, with 99% of timelines ≤10 days. This performance was poorer than expected, considering the redundant nature of timeline transmission. This may be improved by increasing the frequency of timeline transmission.

Monthly sample size of the different parameters varied substantially over the possible 13 month annual deployment period. The number of seals that contributed data ranged from 27 in June to only 3 the following July, with most dropping out by May (Figure 2). Depth, duration, and time-at-depth histograms had monthly sample size ranges of 48-833, 47-827, and 55-824, respectively. Pooled location sample size ranged from 660 in October to 37 during June of the second year. These are important considerations for the interpretation of these data.

We identified several sources of data collection and transmission errors. Surface timelines contained an error that required us to discard the final time interval (23:40-23:59:59) of each day. We also re-discovered a long-standing flaw in Argos/CLS processing which causes some of the 2-byte data words in our dive data to be coded as hexadecimal instead of decimal. The SATPAK software automatically repaired most of these errors, but the remainder must be fixed by alternate means. We are investigating fixes for these problems to be applied before this data set is formally analyzed.

Spatial Haulout Patterns

Harbor seal pups visited at least 28 of the 69 known haulout sites within the minimum convex polygon encompassing all Argos-computed locations for the study period (Figure 1). Two new potential haulout site locations were identified inside Port Hobron and Newman Bay on Sitkalidak Island (Figure 1). Mean daily on-land locations of one animal clustered at these locations, which were > 5 km distant from the next nearest known haulouts. These potential haulout sites should be field-checked to verify actual animal usage. Additional haulout sites may have been visited on days during which SDRs were not transmitting, especially in areas on the fringes visited by few seals.

We computed the straight-line distance between consecutive harbor seal haulout bouts, and this mean inter-haulout distance ranged from 7-850 km (Table 5). Seals spent approximately 60% of their time hauled out, and haulouts are the focal points for their foraging trips, so the inter-haulout distance provided a minimum estimate of animal movement between different foraging areas. Of the 16 seal pups for which at least 11 months of data were obtained, cumulative movements ranged from 40 to 850 km, so deployment length did not appear to bias these distance measurements. However, this measure does not appear to be a satisfactory measure of haulout site fidelity, as long-distance dispersal movements comprised of many short haulout-to-haulout hops had similar cumulative distances when compared to seals that made many short trips among nearby haulouts.

Temporal Haulout Patterns

Over the entire deployment period, female pups spent slightly more time hauled out than males, as indicated by surface-timelines (Figure 3) and time-at-surface histogram bins (Figure 4). Proportion of time spent at-sea increased rapidly from deployment through August, then remained fairly constant until mid-winter, where a slight decrease was observed from February through April (Figure 4).

Surface timelines, grouped by arbitrarily defined seasons ("Summer", June-August; "Autumn", September-November; and "Winter", December-February), described a substantial difference in diurnal haulout pattern. During Summer, animal haulouts peaked between 12:00 and 16:00 LT, and at-sea activity peaked at 05:00 (Figure 5). Autumn haulout showed a relatively balanced diurnal pattern. Winter diurnal haulout activity was nearly opposite the summer pattern, with peak at-sea activity occurring between 12:00 and 15:00 LT.

During formal analysis, surface-timeline data will identify the start-time and duration of individual haulout bouts and help to better interpret other measures of haulout and dive behavior. The comparison of bout start/end time with local daylight and tide cycles may also provide insight into the proximate cues harbor seal pups use to begin foraging.

Diving Behavior

We received 6,407 unique Maximum-Depth histograms, which represented 466,410 individual dives. The 6,361 unique Dive Duration histograms represent 463,360 individual dives, and the 6,278 unique Time-at-Depth histograms describe 37,688 hours of animal activity above and below the surface. Maximum daily depths, which are an absolute measure of harbor seal diving ability, increased over time from <150 meters shortly after deployment to >250 meters by August (Figure 6). During December 1998, a male (98-04) dove to 308 meters in Shelikof Strait, the deepest dive recorded during this study. For male harbor seal pups, maximum dive depth (Figure 7**)** and dive duration (Figure 8**)** increased steadily from deployment until late winter. Female seals showed similar trends, but interestingly made shallower and shorter dives than the males during the February through May period. For both males and females, as dives became longer and deeper, daily dive frequency (Figure 9) decreased. Dive frequency peaked in August-September at about 14 dives/hour. The decrease in mean dive depth during April-June is coincident with the decrease in maximum daily dive depths.

While overall trends were slight, pups tended to concentrate shallower dives (12-36 meters) between late afternoon and early morning (LT) and appeared to dive deepest (>50 meters) during dawn and dusk periods (Figure 10). As expected, dive frequency was less during daylight hours when seals dove deeper and spent relatively more time within the deeper depth categories (Figure 11). Interestingly, dive duration (Figure 12) did not track dive depth and time-at-depth trends, as dives tended to be longer during the night and dawn hours. Synthesis of the dive and haulout data may explain this phenomenon.

Locations and Movements

At-sea locations for harbor seal pups tagged at Tugidak Island were spread over 80,470 km^2 of water area (minimum convex polygon method, Figure 13). Most mean daily locations (89.6 %) fell within the continental shelf (at the 200 meter depth contour), and the majority of locations over the shelf were grouped in areas shallower than 200 meters. However, a significant number of locations are present over the deep submarine canyon (< 200m) leading from near Chirikof Island into Shelikof Strait (Figure 13). Overall, 55% of at-sea locations fall in areas $\geq$ 20 meters deep, and 99% of locations lie over areas $\leq$ 280 meters deep. A histogram of location distribution by depth of seafloor indicates that locations cluster at the 80 meter depth, 160 meter depth, and the 200 to 240 meter depth range; depths $\leq$ 1 meter were excluded from this summary. The feasibility of determining whether at-sea locations represent transit or foraging activity will require further study. This will depend on developing methods to overcome the difference in temporal scale between locations and summarized dive histograms.

Mean daily locations of individual seal pups were examined (Appendix, Figures 1 – 27), and visually grouped by region to identify general movement patterns. There did not appear to be a "typical" movement pattern, but 4 general patterns of movement emerged from inspection of the inter-region movement data (Appendix, Tables 1 - 27). Some pups (98-11, 98-13) remained in the immediate vicinity of Tugidak Island for the entire deployment period. Others (99-6, 99-12) made frequent short movements between Tugidak Island and nearby haulouts. Several animals (98-10, 98-18, 99-17, 99-19) made multiple long-distance, short-duration movements between Tugidak Island and outlying haulouts. Few animals (97-3, 98-14) dispersed long distances from Tugidak Island and remained away for long (>2 month) periods. Selection of these distant regions should be corroborated with inter-haulout movement measures (Table 4) and correlated with habitat variables.

At-sea locations were most concentrated near the Tugidak-Sitkinak-Geese Islands group and off Mount Myrtle Island (Figure 1 and Figure 13), yet several other at-sea location groupings appear worthy of further study. Linear concentrations of locations from 7 animals appear about 50 km off the northwest and southeast shore of Chirikof Island, generally along the 150 meter depth contour. Five animals used an area 60 km west of Chirikof Island. Another linear concentration appears between Mount Myrtle Island haulout and a point 40 km northwest of Tugidak Island. Smaller groupings of locations from 6 animals are evident about 100 km off the east coast of Kodiak Island, and throughout the deep canyon running out of Shelikof Strait. Harbor seal pups appeared to use these areas throughout the year. A quantitative analysis of at-sea habitat selection will better describe harbor seal usage of these areas.

SUMMARY

The objectives of this study were to describe patterns of harbor seal pup haulout usage, describe pup movement and diving behavior development during the first year of life, and describe the habitat features of areas and depths used for feeding by harbor seal pups. The data collected between 1997-2000 from pups captured at Tugidak Island appeared to be sufficiently consistent, with the different dive, location, and surface timeline sample sizes varying in more or less similar fashion over time. Sample size (both animal and data sampling unit counts) is biased toward the earlier months of life, and must be normalized before analysis. The last 3 months of deployment in particular had only 22% the sample size of the first 3 months. Several errors were identified in the data set that will require correction before analysis.

Dive and haulout behavior data showed clear seasonal differences. Diving activity increased rapidly as time on the haulout decreased in the 2 months following instrument deployment, then remained relatively constant until a small increase in late winter. Diurnal differences in haulout behavior were also evident between the summer and winter seasons. Diurnal differences in dive and haulout behavior were otherwise less obvious. Harbor seal at-sea locations were concentrated above the continental shelf (< 200 meters deep), with several distinct clusters of activity evident throughout the area. Most locations were recorded in the vicinity of known haulouts, and animals utilized 40% of known haulouts in the study area, as well as 2 potential new haulouts. Location counts showed clusters above 80, 160, and 200-240 meter depth ranges. The presence of distinct at-sea clusters showed the potential for comparing animal presence data with relatively small-scale habitat data. Spatial haulout usage patterns provided a complete picture of animal site preference over time and a relatively reliable estimate of animal presence within particular regions. Inter-haulout movements provided minimum movement estimates between different foraging areas. The general trends identified by this summary should provide guidance for future statistical analyses designed to focus on specific seals, geographic areas, and periods of time, in an effort to meet the objectives of this study.

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Table 1. Capture site and date, sex, mass, size (standard length and axillary girth), and satellite-linked time-depth recorder (SDR) PTT-ID number for 72 harbor seal pups from Tugidak Island, Alaska, 1997-1999.

Specimen	Capture Site	Date	Sex	Mass(kg)	SL (cm)	AXG (cm)	SDR
PV97TUG01	Tugidak Southwest Beach	25-Jun-97	M	27.5	97.0	n/a	5039
PV97TUG02	Tugidak Southwest Beach	25-Jun-97	M	26	92.0	78.5	5049
PV97TUG03	Tugidak Southwest Beach	25-Jun-97	M	26.5	94.5	80.0	5050
PV97TUG04	Tugidak Southwest Beach	25-Jun-97	F	31	90.0	87.0	3089
PV97TUG05	Tugidak Southwest Beach	26-Jun-97	F	23.5	86.0	79.0	5048
PV97TUG06	Tugidak Southwest Beach	26-Jun-97	M	28.1	98.0	84.0	5043
PV97TUG07	Tugidak Southwest Beach	26-Jun-97	M	30.2	95.0	80.0	5044
PV97TUG08	Tugidak Southwest Beach	26-Jun-97	M	30.4	98.0	86.0	5041
PV97TUG09	Tugidak Southwest Beach	26-Jun-97	M	29.5	95.5	86.0	
PV97TUG10	Tugidak Southwest Beach	26-Jun-97	F	26	101.0	79.5	3090
PV97TUG11	Tugidak Southwest Beach	27-Jun-97	M	29.3	94.0	87.0	5051
PV97TUG12	Tugidak Southwest Beach	27-Jun-97	M	30.1	93.0	83.0	
PV97TUG13	Tugidak Southwest Beach	27-Jun-97	F	29.5	99.0	83.0	
PV97TUG14	Tugidak Southwest Beach	27-Jun-97	M	18.3	79.0	66.0	
PV97TUG15	Tugidak Southwest Beach	27-Jun-97	F	24.4	87.0	81.0	
PV97TUG16	Tugidak Southwest Beach	27-Jun-97	F	25.1	91.0	78.5	
PV97TUG17	Tugidak Southwest Beach	27-Jun-97	F	25.5	97.0	82.0	
PV97TUG18	Tugidak Southwest Beach	28-Jun-97	M	19.4	86.0	68.0	
PV97TUG19	Tugidak Southwest Beach	28-Jun-97	M	30.8	100.0	87.0	
PV97TUG20	Tugidak Southwest Beach	28-Jun-97	M	30.8	98.0	88.0	
PV98TUG01	Tugidak Southwest Beach	24-Jun-98	M	27.5	96.0	85.0	2085
PV98TUG02	Tugidak Southwest Beach	24-Jun-98	M	33.0	93.5	82.0	5044
PV98TUG03	Tugidak Southwest Beach	24-Jun-98	F	24.9	95.0	80.0	
PV98TUG04	Tugidak Southwest Beach	24-Jun-98	M	28.6	107.0	88.0	2089

Table 1. Continued

Specimen	Capture Site	Date	Sex	Mass(kg)	SL (cm)	AXG (cm)	SDR
PV98TUG05	Tugidak Middle Beach	25-Jun-98	M	17.4	87.0	72.0	
PV98TUG06	Tugidak Middle Beach	25-Jun-98	M	27.9	92.0	87.0	
PV98TUG07	Tugidak Middle Beach	25-Jun-98	F	24.7	91.0	86.0	
PV98TUG08	Tugidak Middle Beach	25-Jun-98	M	25.8	103.0	82.0	
PV98TUG09	Tugidak Middle Beach	25-Jun-98	M	31.5	101.0	96.0	
PV98TUG10	Tugidak South Middle Beach	25-Jun-98	M	27.9	105.0	81.0	2086
PV98TUG11	Tugidak South Middle Beach	25-Jun-98	M	27.5	92.0	88.0	2088
PV98TUG12	Tugidak South Middle Beach	25-Jun-98	F	21.3	94.0	74.0	
PV98TUG13	Tugidak South Middle Beach	25-Jun-98	F	28.9	101.0	87.0	2084
PV98TUG14	Tugidak North-Northeast Beach	26-Jun-98	M	32.5	89.0	90.0	2091
PV98TUG15	Tugidak North Beach	26-Jun-98	F	23.6	90.0	81.0	
PV98TUG16	Tugidak North Beach	26-Jun-98	M	21.4	91.0	78.0	
PV98TUG17	Tugidak North Beach	26-Jun-98	F	32.5	93.0	90.0	2090
PV98TUG18	Tugidak North Beach	26-Jun-98	F	28.2	102.0	88.0	2087
PV98TUG19	Tugidak North Beach	26-Jun-98	M	20.1	98.0	80.0	
PV98TUG20	Tugidak North Beach	26-Jun-98	M	23.1	96.0	79.0	
PV98TUG21	Tugidak North Beach	26-Jun-98	M	27.2	101.0	82.0	
PV98TUG22	Tugidak North Beach	26-Jun-98	M	37.2	109.0	90.0	
PV98TUG23	Tugidak North Beach	26-Jun-98	M	25.5	101.0	86.0	
PV98TUG24	Tugidak Southwest Beach	27-Jun-98	F	22.6	93.0	78.0	
PV98TUG25	Tugidak Southwest Beach	27-Jun-98	M	21.9	95.0	75.0	
PV98TUG26	Tugidak Southwest Beach	27-Jun-98	F	25.9	96.0	78.0	
PV98TUG27	Tugidak Southwest Beach	27-Jun-98	M	24.8	91.0	80.0	
PV99TUG04	Tugidak Southwest Beach	26-Jun-99	M	32.4		89.0	5046
PV99TUG05	Tugidak Southwest Beach	26-Jun-99	M	36.7	102.0	92.0	
PV99TUG06	Tugidak Southwest Beach	26-Jun-99	F	26.5	97.0	79.0	5043

Table 1. Continued

Specimen	Capture Site	Date	Sex	Mass(kg)	SL (cm)	AXG (cm)	SDR
PV99TUG07	Tugidak Southwest Beach	26-Jun-99	F	30.8	91.0	88.0	5042
PV99TUG08	Tugidak Southwest Beach	27-Jun-99	F	20.9	102.0	75.0	
PV99TUG09	Tugidak Southwest Beach	27-Jun-99	F	28.1	100.0	85.0	5050
PV99TUG10	Tugidak Southwest Beach	27-Jun-99	M	25.3	99.0	79.0	
PV99TUG11	Tugidak South Middle Beach	27-Jun-99	M	23.1	93.0	75.0	
PV99TUG12	Tugidak South Middle Beach	27-Jun-99	F	27.3	96.0	89.0	5040
PV99TUG13	Tugidak South Middle Beach	27-Jun-99	F	25.7	89.0	77.5	5047
PV99TUG14	Tugidak South Middle Beach	27-Jun-99	M	25.7	93.0	77.0	
PV99TUG15	Tugidak South Middle Beach	27-Jun-99	M	37.8	101.0	96.0	
PV99TUG16	Tugidak South Middle Beach	27-Jun-99	M	29.5	97.5	90.5	
PV99TUG17	Tugidak South Middle Beach	28-Jun-99	M	28.6	97.0	81.0	5045
PV99TUG18	Tugidak South Middle Beach	28-Jun-99	F	12.5	89.0	68.0	
PV99TUG19	Tugidak South Middle Beach	28-Jun-99	F	25.4	88.0	80.0	5049
PV99TUG20	Tugidak North-Northeast Beach	28-Jun-99	F	22.3	94.0	77.5	
PV99TUG21	Tugidak North Beach	28-Jun-99	F	25.1	87.0	81.5	
PV99TUG22	Tugidak North Beach	28-Jun-99	M	27.6	102.0	84.0	
PV99TUG23	Tugidak North Beach	28-Jun-99	M	27.8	97.0	81.5	
PV99TUG24	Tugidak North Beach	28-Jun-99	M	30.4	94.0	85.0	
PV99TUG25	Tugidak North Beach	28-Jun-99	M	30.1	97.0	84.5	

Table 2. Performance of satellite-linked time-depth recorders attached to harbor seal pups on Tugidak Island, Alaska, 1997-1999.

SDR	Animal Identifier	Sex	Date Attached	Date of Last Transmission	Total Days Operational	# Days with Locations	Total # of Locations
5039	97-01	M	25-Jun-97	12-Aug-97	48	24	47
5049	97-02	M	25-Jun-97	19-May-98	328	99	242
5050	97-03	M	25-Jun-97	24-Mar-98	272	136	327
3089	97-04	F	25-Jun-97	27-May-98	336	147	311
5048	97-05	F	25-Jun-97	21-Apr-98	299	142	291
5043	97-06	M	26-Jun-97	14-Apr-98	292	35	48
5044	97-07	M	26-Jun-97	30-Jun-97	4	1	3
5041	97-08	M	26-Jun-97	15-May-98	324	56	95
3090	97-10	F	26-Jun-97	21-Jun-98	360	174	355
5051	97-11	M	27-Jun-97	14-Nov-97	140	72	142
2085	98-01	M	24-Jun-98	12-May-99	323	141	450
5044	98-02	M	24-Jun-98	15-Jul-99	385	153	364
2089	98-04	M	24-Jun-98	02-Jan-99	193	71	136
2086	98-10	M	25-Jun-98	26-Apr-99	307	119	292
2088	98-11	M	25-Jun-98	12-Jul-99	382	140	313
2084	98-13	F	25-Jun-98	02-May-99	313	142	458
2091	98-14	M	26-Jun-98	29-Jun-99	369	144	317
2090	98-17	F	26-Jun-98	25-Jul-98	29	18	27
2087	98-18	F	26-Jun-98	31-Mar-99	279	130	402
5048	99-02	M	26-Jun-99	22-Sep-99	88	19	28
5046	99-04	M	26-Jun-99	19-May-00	328	140	362
5043	99-06	F	26-Jun-99	07-Nov-99	134	64	203
5042	99-07	F	27-Jun-99	13-Apr-00	291	111	299
5050	99-09	F	27-Jun-99	27-Jun-99	0	0	0
5040	99-12	F	27-Jun-99	28-Jun-00	367	117	245
5047	99-13	F	27-Jun-99	29-May-00	337	128	265
5045	99-17	M	28-Jun-99	08-Jul-00	376	129	296
5049	99-19	F	28-Jun-99	26-Jun-00	364	119	253

Table 3. Percentage of each Argos-defined location quality class for estimated harbor seal pup locations, by land/sea status and battery type, collected June 1997 – July 2000.

Location Quality Class	Estimated Accuracy	On-Land	At-Sea	M1 Battery	2/3A Battery
3	accuracy < 150 meters	7.6	2.7	3.7	3.1
2	150 m <= accuracy < 350 m	14.3	5.9	7.6	6.8
1	350 m <= accuracy <= 1000 m	29.2	12.6	17.0	13.4
0	accuracy > 1000 m	19.8	10.6	13.5	10.9
A	Undefined	19.9	27.0	24.4	26.7
B	Undefined	9.3	41.2	33.6	38.8

Table 4. Dive and surface-timeline data efficiency and completeness based on 7,291 total active SDR days, for harbor seal pups, 1997-2000. If all possible histograms were received (29,164), there would be 7,291 histograms in each of the 4 6-hour diurnal periods. If all possible timelines were received, there would be 7,291 unique timelines.

Data Type	Count	Percentage of possible samples received	Percentage of Samples Received by Time-of-Day			
			Dawn	Day	Dusk	Night
Maximum Dive Depth Histograms	6407	21.9	26	24	24	25
Dive Duration Histograms	6361	21.1	26	24	25	26
Time-at-Depth Histograms	6278	21.5	26	25	25	26
Surface-Timelines	2020 days	27.7	N/A	N/A	N/A	N/A

Table 5. Summary of harbor seal pup inter-haulout movements during June 1997–July 2000. Distances are the direct, straight-line distance in kilometers between consecutive haulout bouts. Cumulative distance represents the sum of all inter-haulout movements from SDR deployment to SDR failure.

	Distance Between Consecutive Haulout Bouts (km)		
Animal ID	Cumulative	Maximum	Minimum [1]
97-01	7.25	7.25	7.25
97-02	177.75	114.97	10.84
97-03	172.35	94.01	78.34
97-04	173.76	70.60	6.85
97-05	243.16	77.76	2.59
97-06	85.37	85.37	85.37
97-07	*	*	*
97-08	135.43	20.62	4.27
97-10	420.41	137.80	4.27
97-11	32.24	10.84	10.56
98-01	374.81	27.52	6.24
98-02	63.92	10.56	10.56
98-04	451.13	144.39	15.94
98-10	209.96	26.66	4.27
98-11	434.83	10.56	2.59
98-13	98.18	27.72	2.50
98-14	849.98	120.94	2.59
98-17	45.69	24.27	4.35
98-18	226.25	52.06	2.59
99-02	10.56	10.56	10.56
99-04	40.48	20.24	20.24
99-06	129.14	59.80	2.59
99-07	211.28	27.52	4.27
99-09	*	*	*
99-12	510.07	18.55	3.37
99-13	646.53	85.37	10.56
99-17	846.52	187.77	2.59
99-19	153.21	32.42	4.27
Mean	259.6	57.9	12.3

[1] Excluding consecutive haulout bouts at the same haulout location (distance = 0 km).
* SDRs deployed on these animals failed before any inter-haulout movements were recorded.

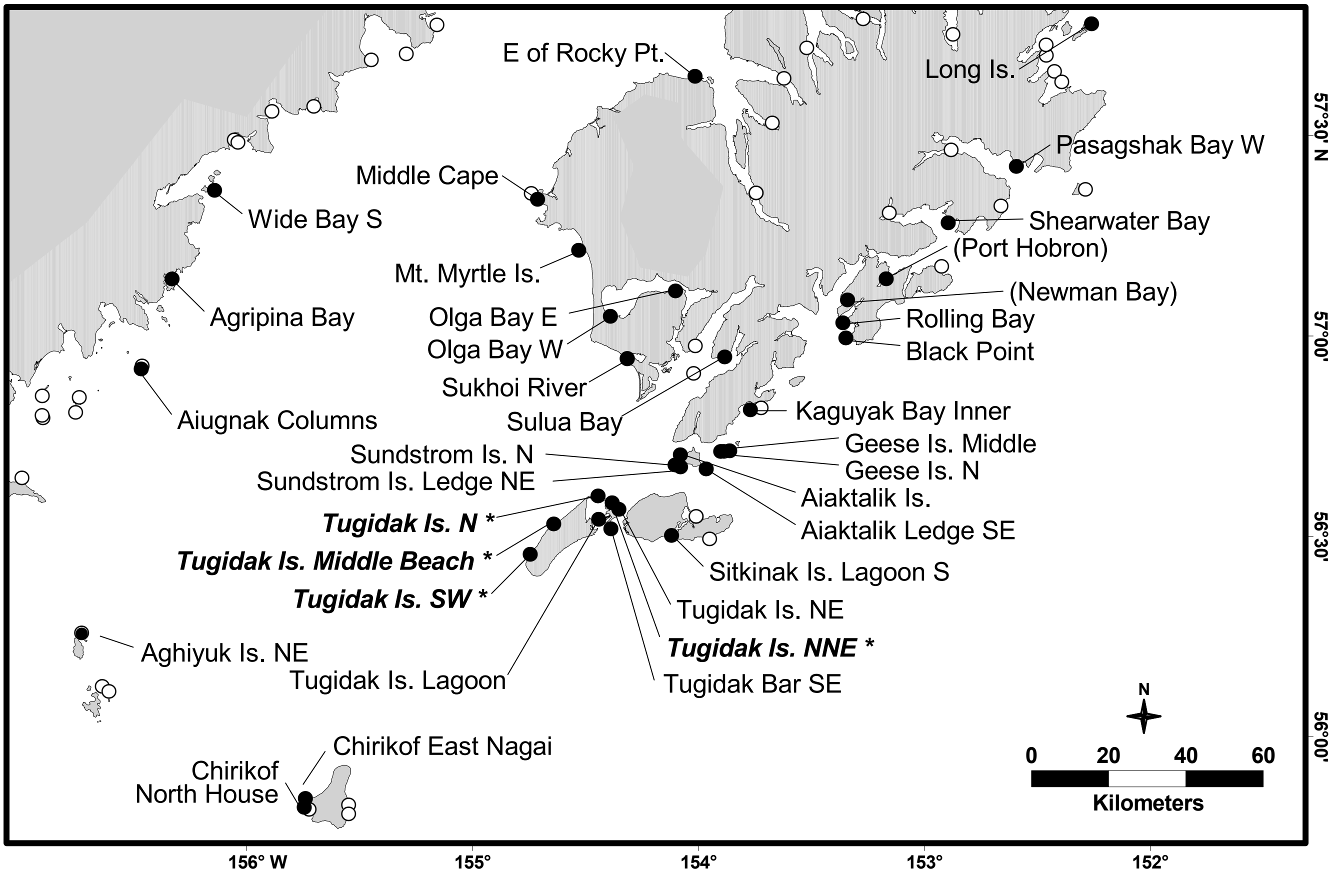

Figure 1. Known harbor seal haulouts (○), and known haulouts visited by monitored harbor seal pups (●) during June 1997- July 2000. General vicinities of 2 potential new haulouts at Port Hobron and Newman Bay are indicated in parenthesis. Capture and release sites (*) are indicated in bold italics.

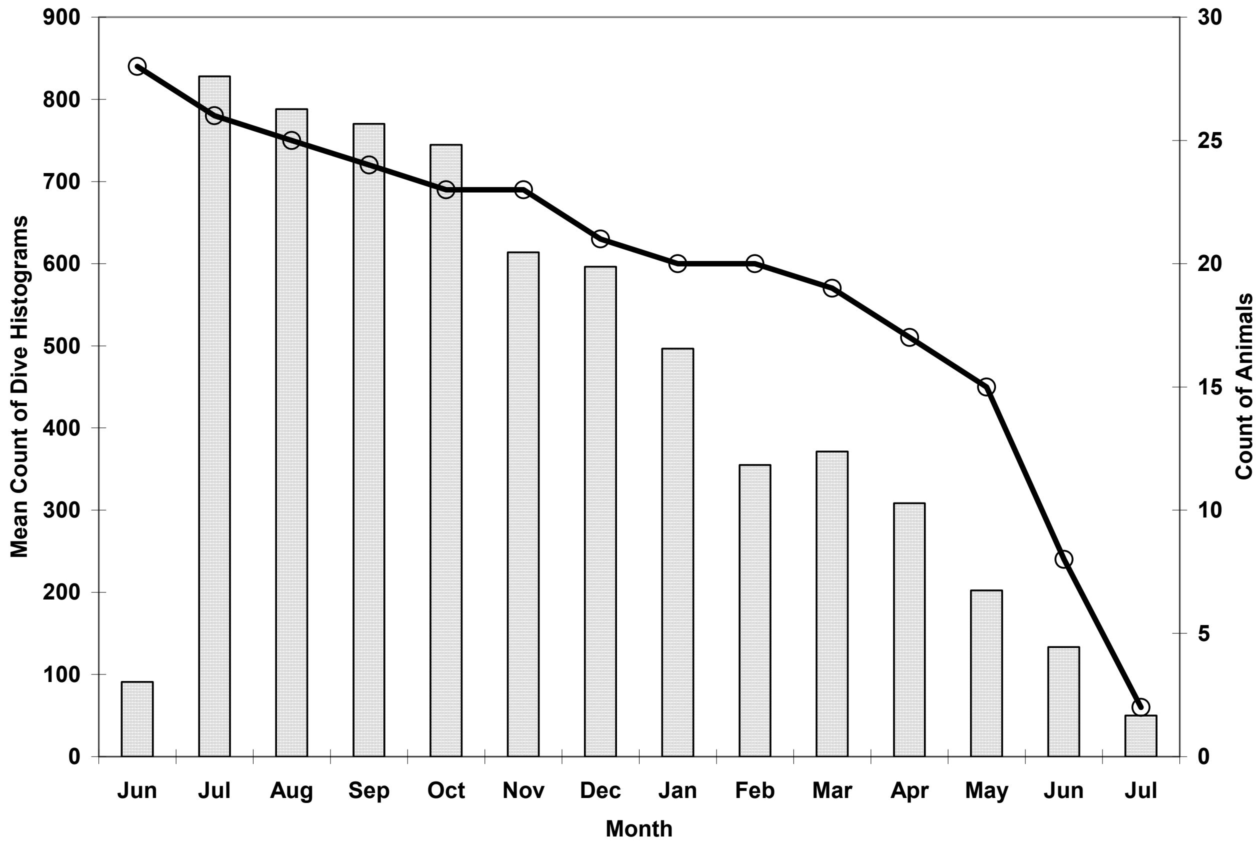

Figure 2. Mean count of the 3 dive histogram types (shaded bars) by month (histograms pooled for all 28 harbor seal pups), and count of seals with actively transmitting SDRs (solid line), June 1997–July 2000. Two types of sample size are relevant to this summary report: the mean count of the 3 dive histogram types per month (pooled for all seals) indicates the size of the dive data sample; and the count of seals with actively transmitting SDRs is used to interpret the dive histogram sample size, and avoid extrapolating results from relatively few seals to the entire population.

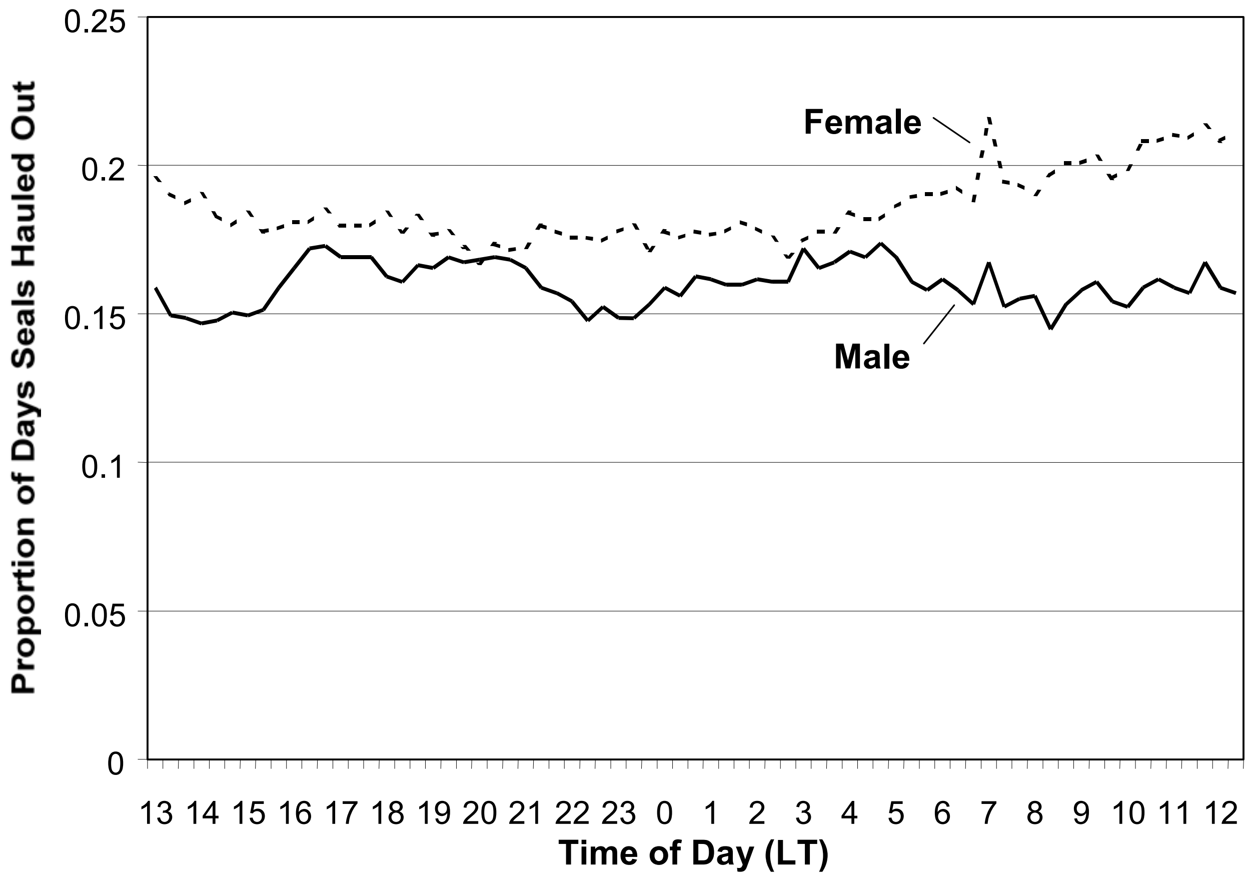

Figure 3. Diurnal trend of the mean proportions of time spent hauled out by male (n=1,070 unique timelines) and female (n=951) harbor seal pups, based on surface-timelines, June 1997–July 2000. The haulout timeline data indicated whether SDRs attached to seals were mostly dry, or mostly wet, in each of 72 20-minute intervals throughout a 24-hour period, recorded midnight-to-midnight UT.

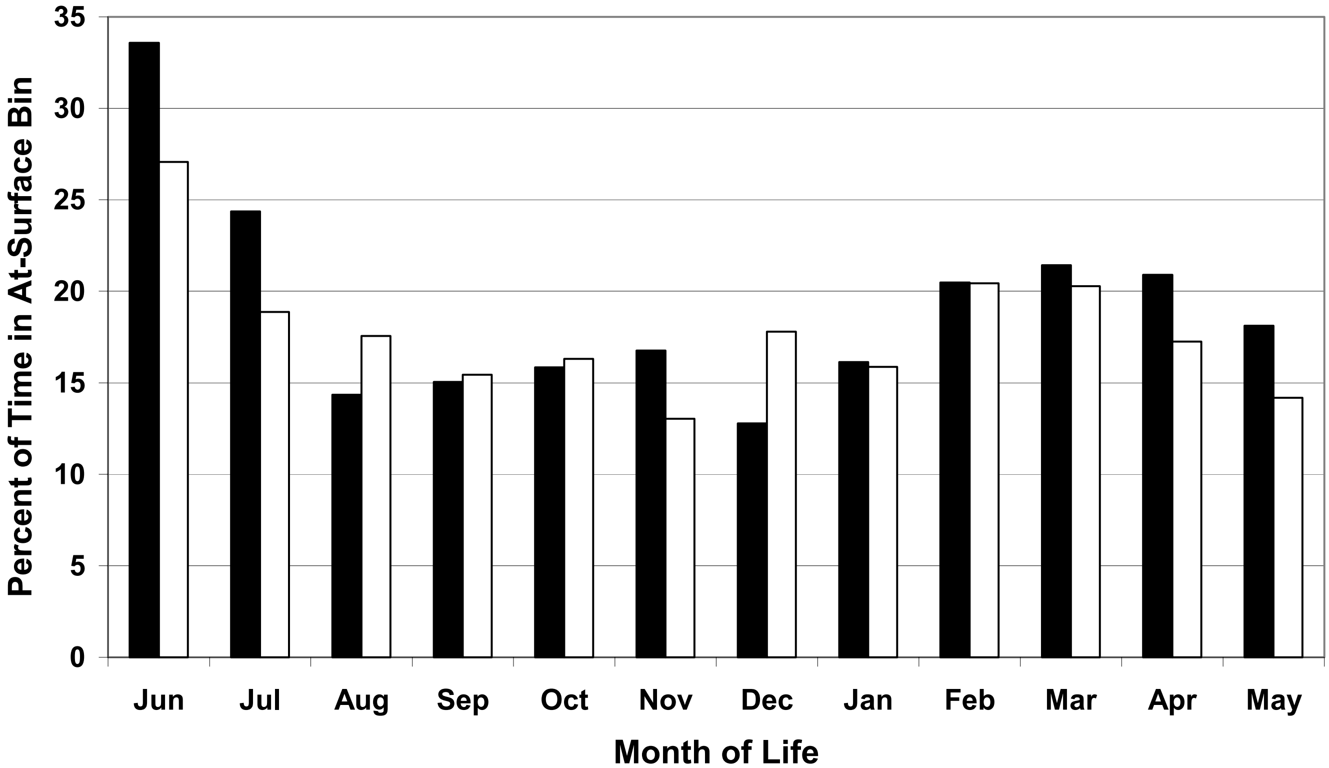

Figure 4. The trend of time spent in the at-surface time-at-depth bin by month. This summary reports the proportion of time seals spent either hauled-out or at-sea but dry. Data from all seals in each month, grouped by male (unshaded) and female (shaded), were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

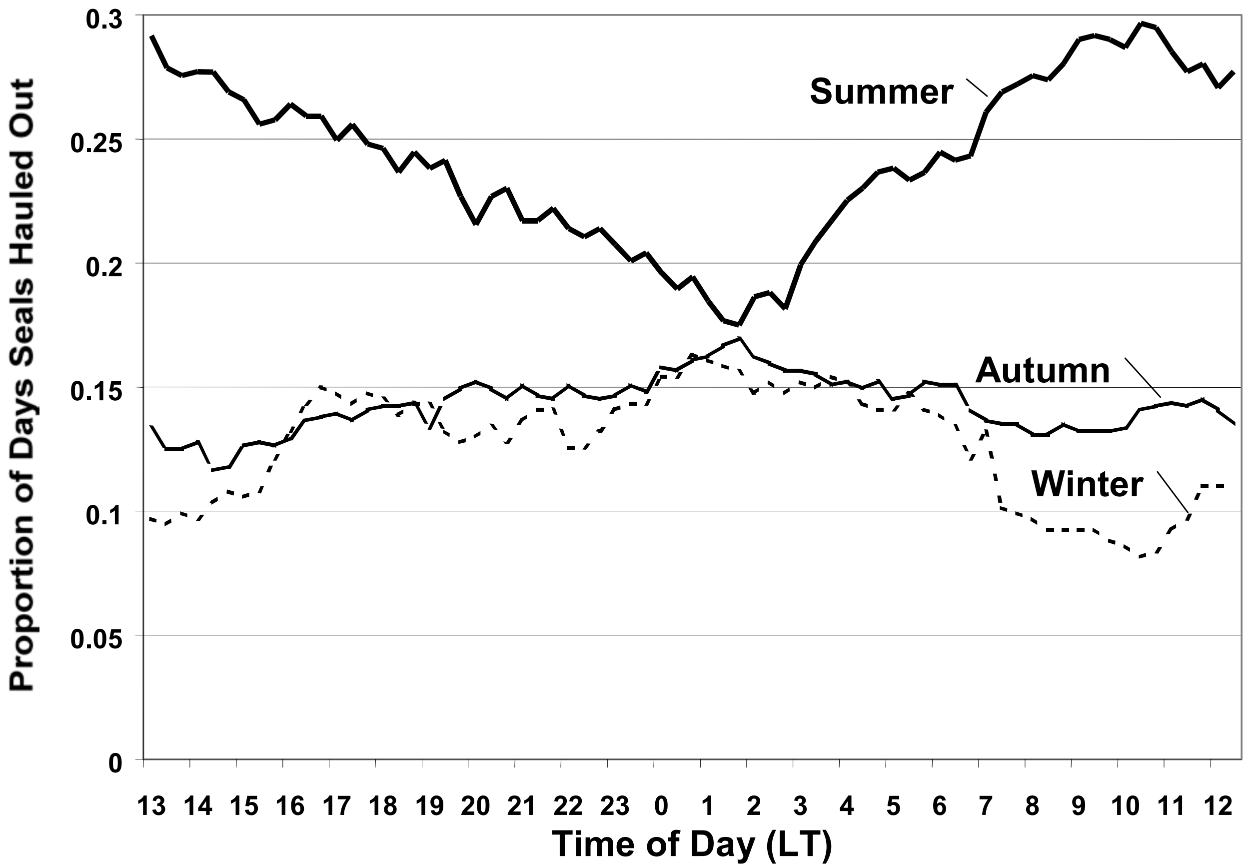

Figure 5. Diurnal trend of the mean proportions of time spent hauled out by harbor seal pups, grouped by season: Summer (June–August, n=617 unique timelines), Autumn (September–November, n=696), and Winter (December–February, n=454). These data were received as haulout timelines, which indicated whether SDRs attached to seals were mostly dry, or mostly wet, in each of 72 20-minute intervals throughout a 24 hour period, recorded midnight-to-midnight UT.

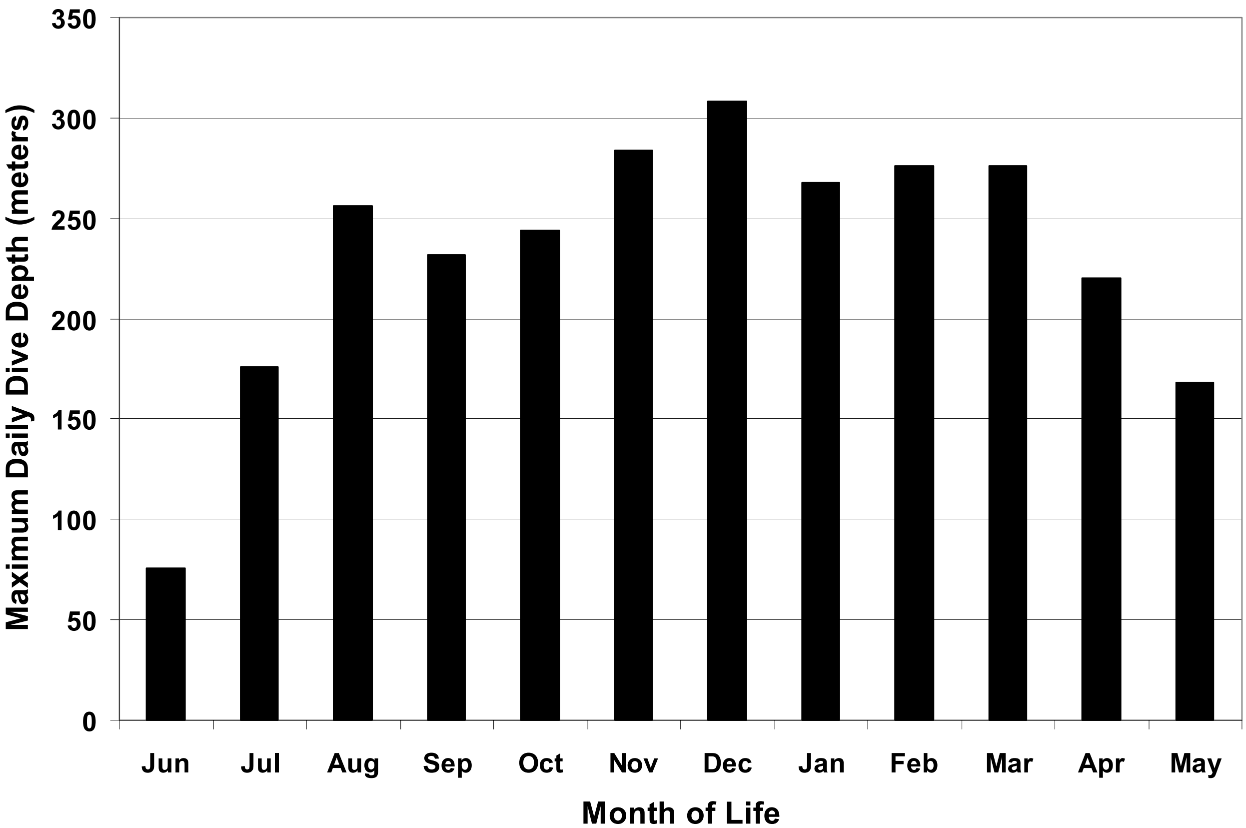

Figure 6. Trend of actual maximum daily depth reached by any harbor seal pup, grouped by month; a maximum dive depth of 308 meters was reached by a male harbor seal pup in December 1998 (SDRs were able to record depths up to 490 meters with 2-meter resolution). The months beyond May of the second year were deleted due to small sample size.

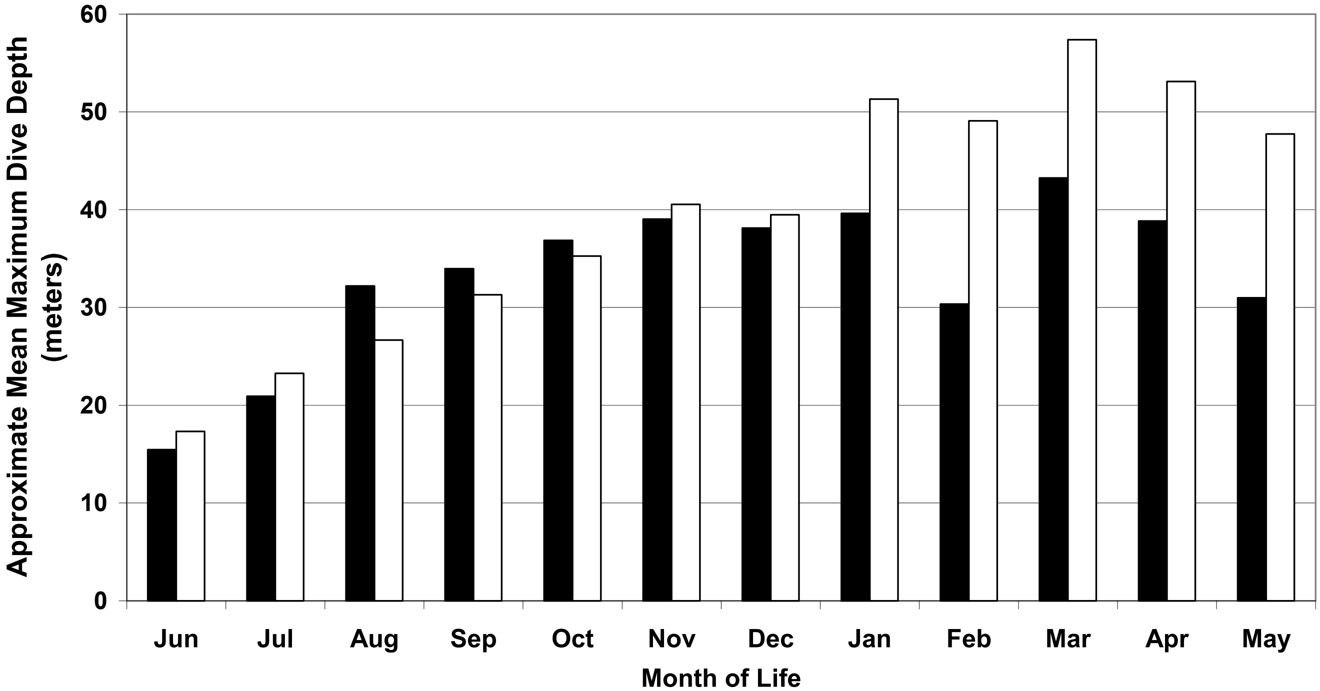

Figure 7. Trend in the mean maximum dive depth by month over the deployment period. To facilitate presentation, approximate monthly mean dive depths were computed by multiplying the count of dives in each maximum depth bin by the mid-point depth of that bin, then calculating a mean to represent each month. Data from all seals in each month, grouped male (unshaded) and female (shaded), were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

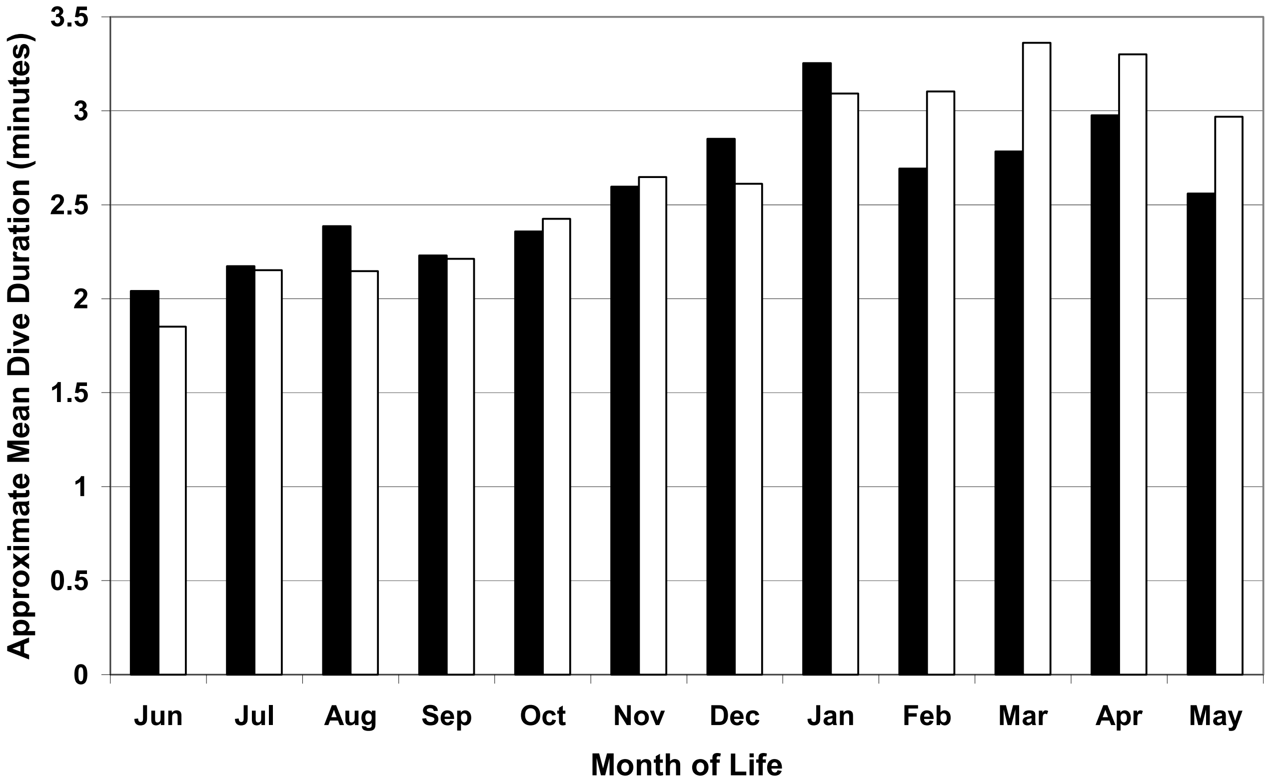

Figure 8. The trend in mean dive duration by month over the deployment period. To facilitate presentation, approximate monthly mean dive durations were computed by multiplying the count of dives in each duration bin by the mid-point time of that bin, then taking a mean to represent each month. Data from all seals in each month, grouped by male (unshaded) and female (shaded), were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

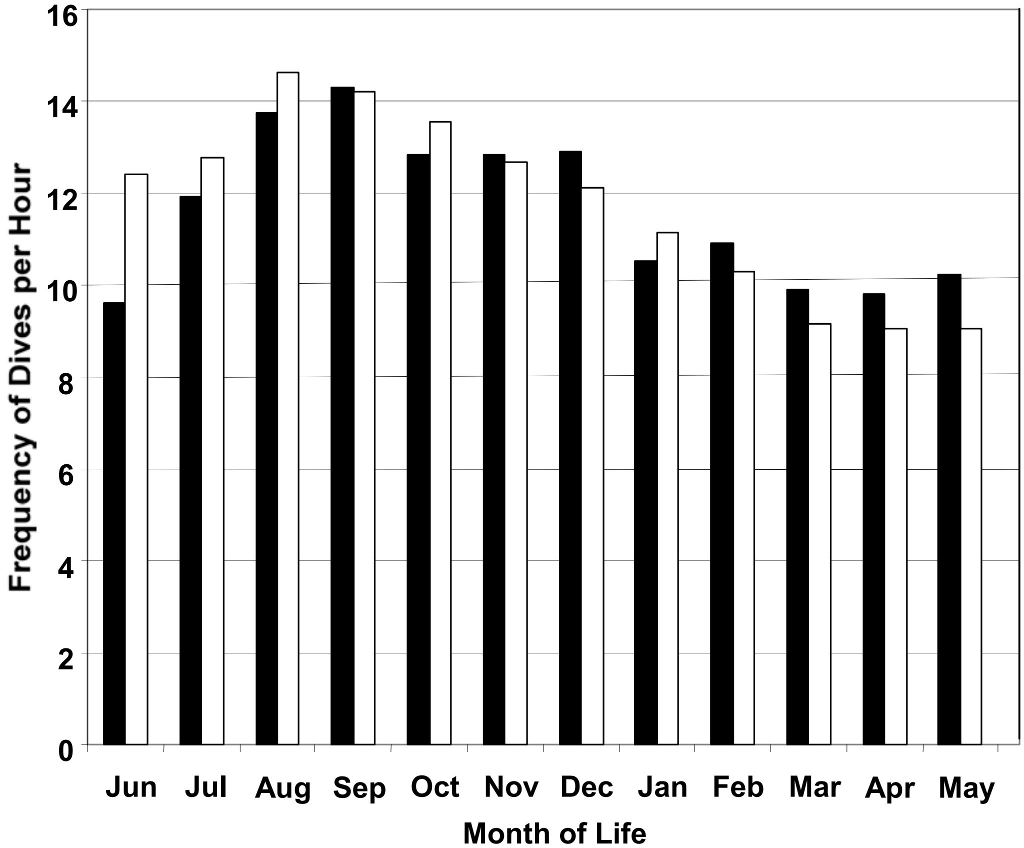

Figure 9. Trend in dive frequency (number of dives/hour) by month over the deployment period for male (unshaded) and female (shaded) harbor seal pups. The months beyond May of the second year were deleted due to small sample size.

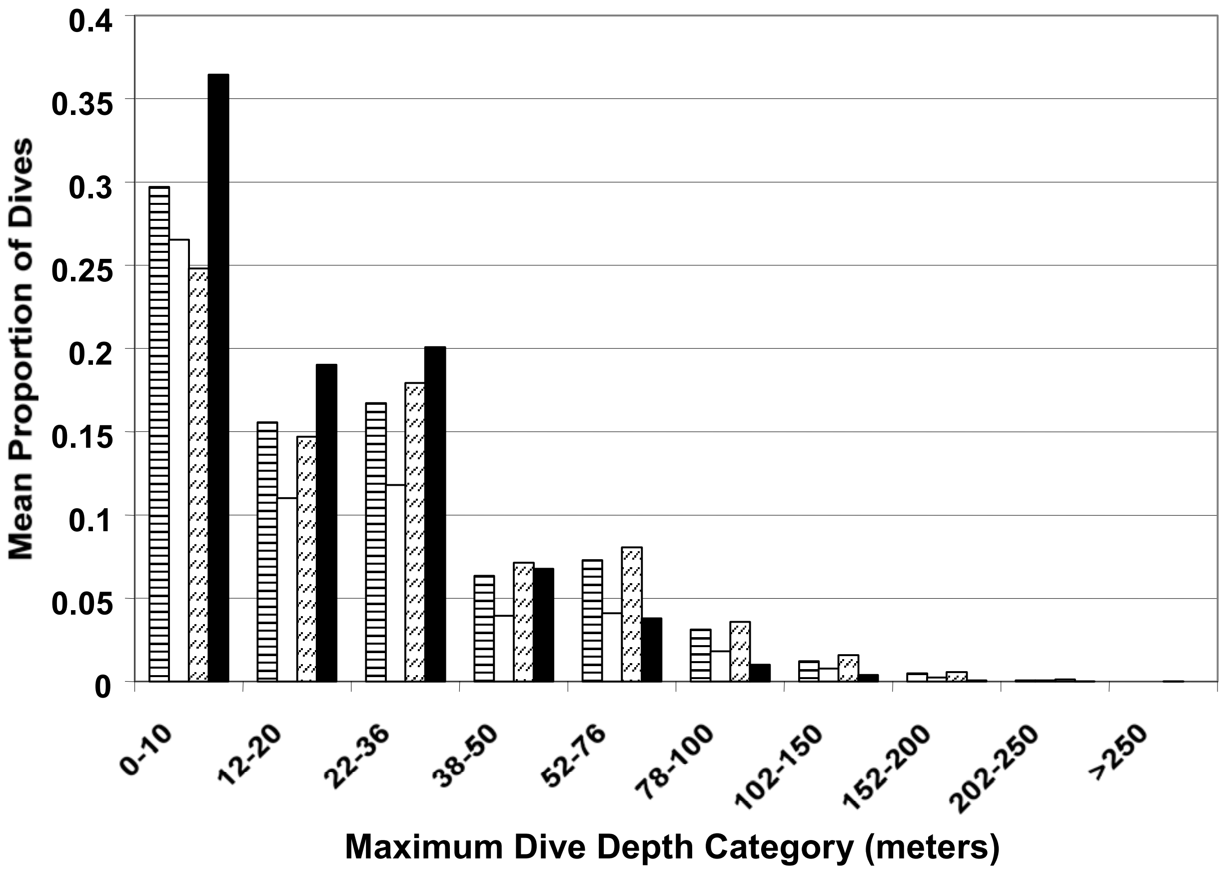

Figure 10. Diurnal trend of maximum dive-depth by 6-hour histogram periods: dawn (horizontal bars), day (white), dusk (diagonal bars), and night (black). This summary indicates how deep harbor seals were diving during different times of day. Data from all seals in each period were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

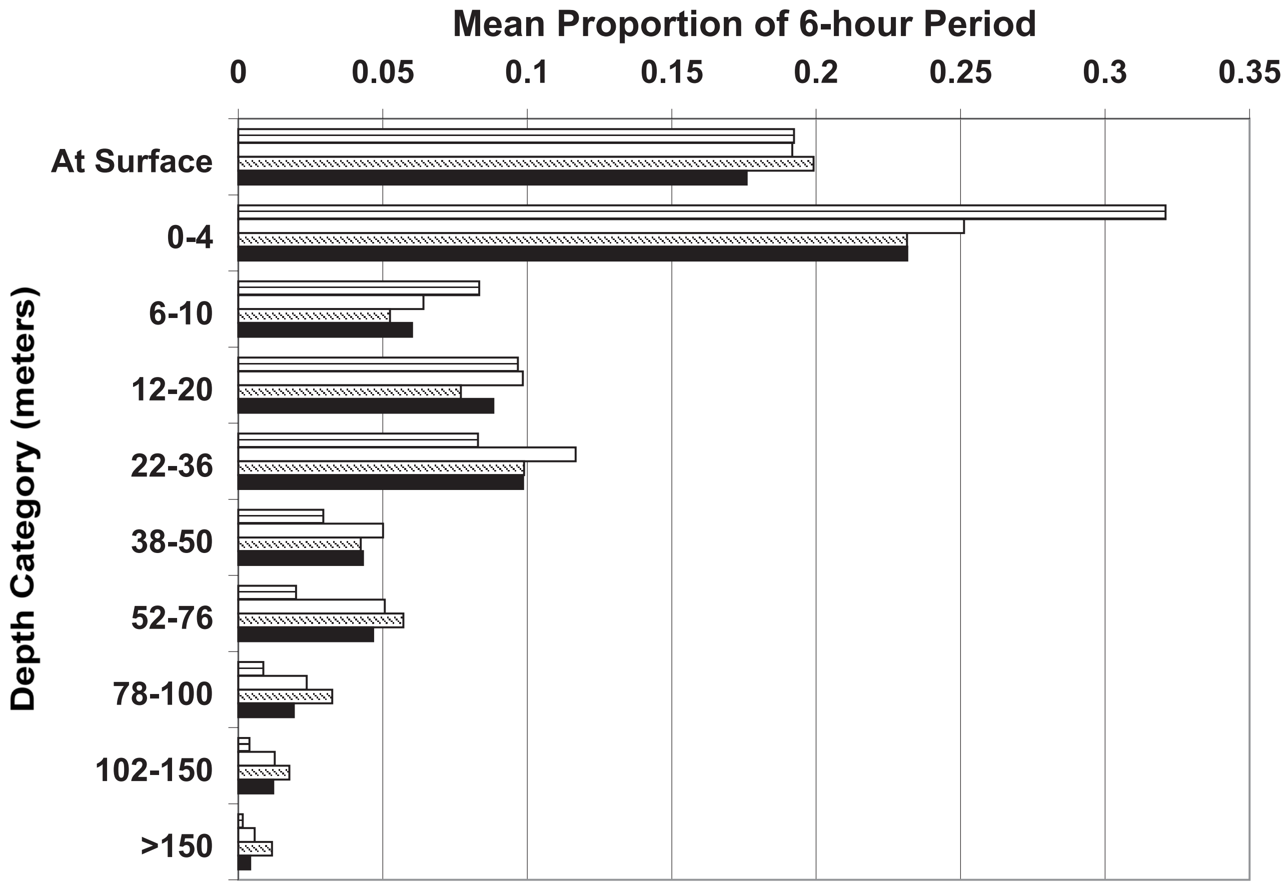

Figure 11. Diurnal trend of time animals spent in depth categories, 6-hour histogram periods: dawn (horizontal bars), day (white), dusk (diagonal bars), and night (black). This time-at-depth summary describes how much time harbor seals spent in each of 10 depth categories. Data from all seals in each period were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

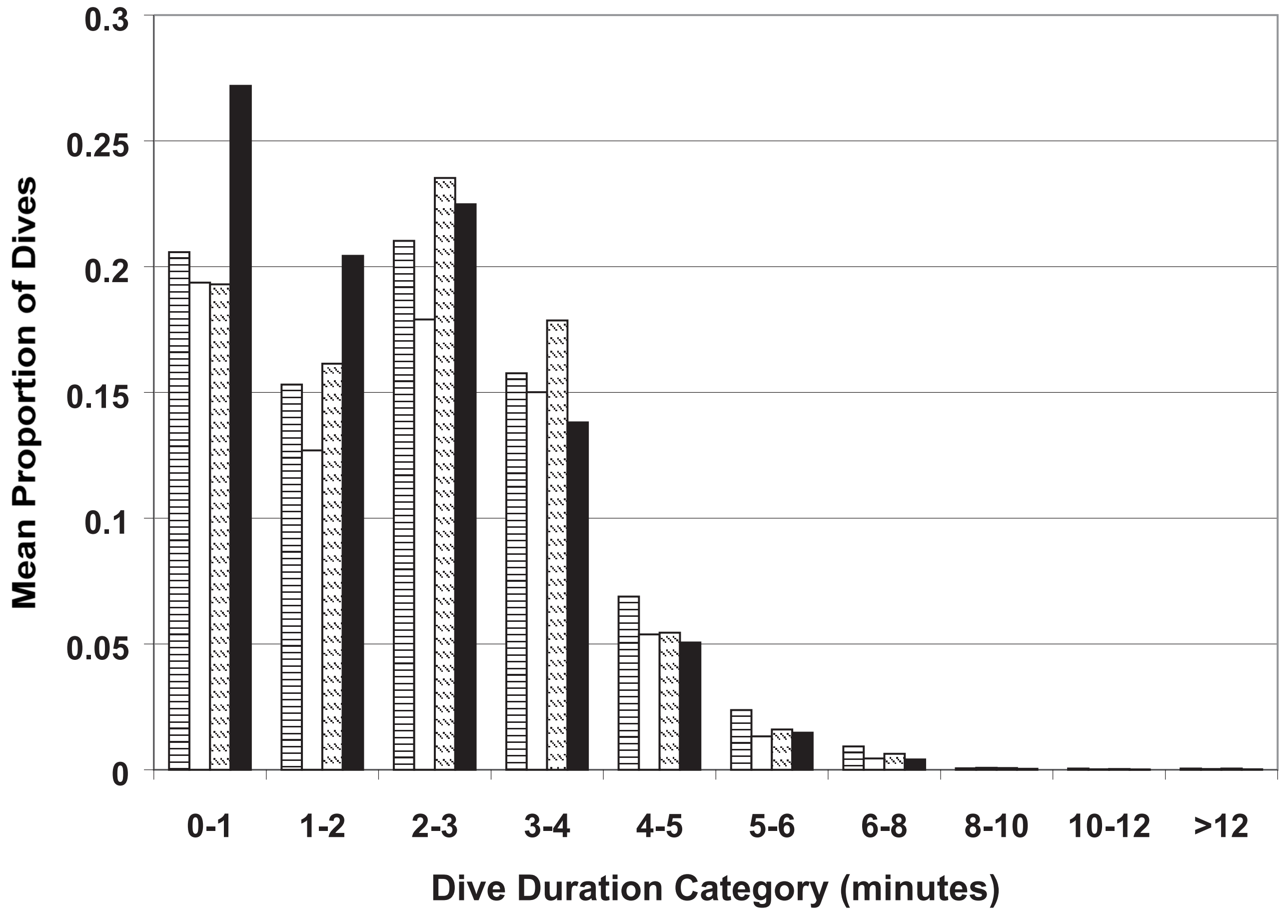

Figure 12. Diurnal trend of dive duration by 6-hour histogram periods: dawn (horizontal bars), day (white), dusk (diagonal bars), and night (black). Data from all seals in each period were pooled for this summary. Months beyond May of the second year were deleted due to small sample size.

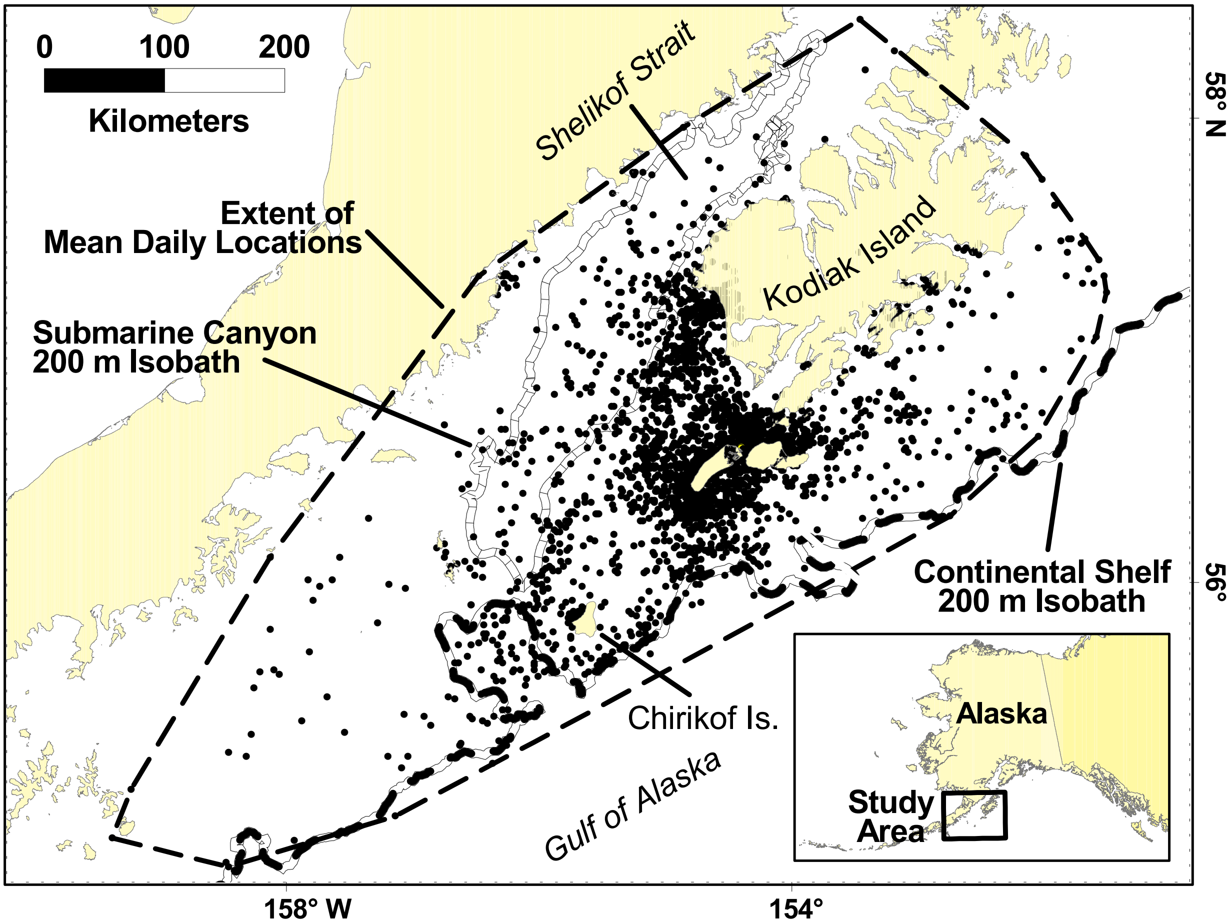

Figure 13. Spatial distribution of all mean daily locations estimated for harbor seal pups tagged on Tugidak Island, Alaska, June 1997-July 2000. Extent of all locations is indicated by a minimum convex polygon (80,470 km^2 water area). Two hundred meter depth isobath indicates the approximate continental shelf edge and the submarine canyon between Shelikof Strait and the Gulf of Alaska proper.